# MAIZE RESPONSE TO NITROGEN FERTILIZATION TIMING IN TWO TILLAGE SYSTEMS IN A SOIL WITH HIGH ORGANIC MATTER CONTENT[1]

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## SUMMARY

**No-tillage systems, associated to black oat as preceding cover crop, have been increasingly adopted. This has motivated anticipated maize nitrogen fertilization, transferring it from the side-dress system at the stage when plants have five to six expanded leaves to when the preceding cover crop is eliminated or to maize sowing. This study was conducted to evaluate the effects of soil tillage system and timing of N fertilization on maize grain yield and agronomic efficiency of N applied to a soil with high organic matter content. A three-year field experiment was conducted in Lages, state of Santa Catarina, from 1999 onwards. Treatments were set up in a split plot arrangement. Two soil tillage systems were tested in the main plots: conventional tillage (CT) and no-tillage (NT). Six N management systems were assessed in the split-plots: S1 – control, without N application; S2 – all N (100 kg ha$^{-1}$) applied at oat desiccation; S3 – all N applied at maize sowing; S4 – all N side-dressed when maize had five expanded leaves (V5 growth stage); S5 – 1/3 of N rate applied at maize sowing and 2/3 at V5; S6 – 2/3 of nitrogen rate applied at maize sowing and 1/3 at V5. Maize response to the time and form of splitting N was not affected by the soil tillage system. Grain yield ranged from 6.0 to 11.8 t ha$^{-1}$. The anticipation of N application (S2 and S3) decreased grain yield in two of three years. In the rainiest early spring season (2000/2001) of the experiment, S4 promoted an yield advantage of 2.2 t ha$^{-1}$ over S2 and S3. Application of total N rate before or at sowing decreased the number of kernels produced per ear in 2000/2001 and 2001/2002 and the number of ears produced per area in 2001/2002, resulting in reduced grain yield. The agronomic efficiency of applied N (kg grain increase/kg of N applied) ranged from 13.9 to 38.8 and was always higher in the S4 than in the S2 and S3 N systems. Short-term N immobilization did not reduce grain yield when no N was applied before or at maize sowing in a soil with high organic matter content, regardless of the soil tillage system.**


**Index terms: *Zea mays*, nitrogen, immobilization, leaching, grain yield.**

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**RESUMO**: *RESPOSTA DO MILHO À ÉPOCA DE APLICAÇÃO DO FERTILIZANTE NITROGENADO EM DOIS SISTEMAS DE CULTIVO NUM SOLO COM ALTO TEOR DE MATÉRIA ORGÂNICA*

*O aumento na adoção do sistema de semeadura direta, associado à freqüente utilização da aveia-preta como cobertura de inverno, tem estimulado a antecipação da fertilização nitrogenada para a cultura do milho. Esta tem sido transferida da cobertura, feita quando a planta tem cinco a seis folhas expandidas, para o período de dessecação da cobertura de inverno ou da semeadura do milho. Este trabalho foi conduzido objetivando avaliar os efeitos de dois sistemas de preparo de solo e da época de aplicação de N sobre o rendimento de grãos do milho e a eficiência agronômica do N aplicado num solo com alto teor de matéria orgânica. Instalou-se um experimento num Nitossolo Vermelho, com 54 g kg$^{-1}$ de matéria orgânica, em Lages-SC, durante as estações de crescimento de 1999/2000, 2000/2001 e 2001/2002. Os tratamentos foram dispostos no delineamento experimental de parcelas sub-divididas. Dois sistemas de preparo de solo foram avaliados na parcela principal: convencional e semeadura direta. Seis sistemas de manejo da adubação nitrogenada foram avaliados nas subparcelas: S1 – testemunha sem N; S2- todo o N (100 kg ha$^{-1}$) aplicado na dessecação da aveia; S3 – todo o N aplicado na semeadura do milho; S4 – todo o N aplicado quando o milho tinha cinco folhas expandidas (estádio V5); S5 – um terço do N aplicado na semeadura do milho e dois terços no estádio V5; S6 – dois terços do N aplicados na semeadura e um terço em V5. A resposta do milho à época e ao tipo de fracionamento da adubação nitrogenada não foi afetada pelo sistema de preparo do solo. O rendimento de grãos variou de 6,0 a 11,8 t ha$^{-1}$. A antecipação da fertilização nitrogenada (S2 e S3) diminuiu o rendimento de grãos em duas das três safras. Na estação de crescimento com a primavera mais chuvosa (2000/2001), a produtividade obtida em S4 foi 2,2 t ha$^{-1}$ maior do que a registrada em S2 e S3. A aplicação de todo o N antes ou durante a semeadura do milho diminuiu o número de grãos por espiga em 2000/2001 e 2001/2002, bem como número de espigas por planta em 2001/2002, contribuindo para reduzir o rendimento de grãos. A eficiência agronômica do N aplicado (kg de aumento no rendimento/kg de N aplicado) variou de 13,9 a 38,8 e foi sempre maior em S4 do que em S2 e S3. A imobilização temporária de N não reduziu o rendimento de grãos do milho quando não se aplicou N antes ou durante a semeadura do milho num solo com alto teor de matéria orgânica, independentemente do sistema de preparo do solo.*

*Termos de indexação:* Zea mays*, nitrogênio, imobilização, lixiviação, rendimento de grãos.*

## INTRODUCTION

Maize requires high N amounts to warrant high yields. The crop takes up between 20 and 25 kg of soil N per ton of grain (Muzilli & Oliveira, 1992; Sangoi et al., 2001a). Nitrogen is the most unstable nutrient in the soil and is affected by several reactions such as volatilization, leaching, denitrification and immobilization. The diversity of reactions that influence N dynamics makes timing of N application a crucial issue to balance N requirements for optimum maize growth and to minimize N losses to the environment (Dinnes et al., 2002).

Recommended N rates for maize in Brazil range from 0 to 200 kg ha$^{-1}$, depending on the soil organic matter, the kind of rotation system, the type of preceding crop and the producer's yield expectation (Amado et al., 2002). From the whole rate, 10 to 30 kg ha$^{-1}$ is applied at sowing and the rest when plants present five to six expanded leaves and are 40 to 60 cm high (Comissão de Fertilidade do Solo-RS/SC, 2004). This timing of N fertilization was proposed based on field experiments conducted mostly in the conventional (chisel) tillage system (Ceretta & Fries, 1997).

A strong shift towards the no-tillage system has occurred during the last 20 years in Brazil. This change affects some soil characteristics, such as moisture content and temperature, which may also influence N dynamics (Torbert et al., 2001). No-tillage normally increases short-term N immobilization (Torbert & Wood, 1992; Ernani, 2003). Furthermore, the $O_2$ amount of soils under no-tillage is lower than in ploughed and harrowed soils where soil organic matter mineralization is increased (Bayer & Mielniczuk, 1997). Higher immobilization and lower mineralization may contribute to decrease N availability in no-tillage maize during the crop establishment (Ernani et al., 2002).

Black oat (*Avena strigosa*) is presently most used as cover crop preceding maize in southern Brazil. It has low N contents and high C/N ratio. This may enhance N immobilization in the short term, impairing the early growth of the succeeding crop (Ceretta et al., 2002b; Kuo & Jellum, 2002). The increased use of no-tillage, frequently associated to black oat as preceding cover crop, has stimulated the proposal of new alternatives regarding the management of N fertilization for maize in these conditions. This new approach involves the anticipation of N fertilization, transferring it from the traditional side-dress carried out in V5-V6 to the time of winter cover crop desiccation or maize sowing (Sá, 1997; Lech, 2001).

Nitrogen application before or at planting may increase N availability in the soil during early plant growth, mitigating potential immobilization effects caused by the high C/N ratio of oat straw (Ceretta & Fries, 1997). In addition, it may decrease the disparity of yield losses due to N stress if rainy springs delay the planned side-dress application time (Scharf et al., 2002). Conversely, the anticipation of N fertilization may favor N loss by leaching due to the low N uptake capacity of maize in early growth stages (Blackmer et al., 1992; Scherer, 2001). Results of experiments comparing the effects of pre-sowing, sowing and side-dress N applications on maize performance in Brazil are highly variable, depending on weather conditions, soil characteristics, planting date and type of fertilizer application. Most of the information gathered on this issue by Argenta et al. (1999), Bortolini et al. (2001), Ceretta et al. (2002a,b) and Wolshick et al. (2002) is based on studies carried out in soils with low organic matter content (less than 50 g $kg^{-1}$).

The definition of N application timing and rate that precisely match maize needs under different environmental conditions and soil types is very important since these factors improve nutrient uptake, decreasing N losses (Androski, 2000). This work was carried out to evaluate the effects of soil tillage systems and timing of N fertilization on maize grain yield and on the agronomic efficiency of applied N described by Mosier et al. (2004) in a soil with high organic matter content.

## MATERIAL AND METHODS

The experiment was conducted in Lages - SC, southern Brazil, in the growing seasons of 1999/2000, 2000/2001 and 2001/2002 on an Oxisol (Hapludox). The soil organic matter content was determined by wet combustion with dichromate = 54 g $kg^{-1}$; clay content = 520 g $kg^{-1}$; P (Mehlich-1) = 24 mg $kg^{-1}$; K (Mehlich-1) = 330 mg $kg^{-1}$; water pH = 5.8; Ca = 9.5 $cmol_c$ $kg^{-1}$; and Mg = 2.5 $cmol_c$ $kg^{-1}$. The experimental area had never been cultivated until spring 1997. Preceding the establishment of our trial, two tomato (*Lycopersicum esculentum* Mill.) crops were grown. The soil was slightly disk-harrowed before planting tomato in both growing seasons.

The treatments were arranged in a randomized complete block design, in split plots with four replications. Two soil tillage systems were tested in the main plots: conventional tillage (CT), using moldboard plowing (twice) and disk harrowing (twice) to incorporate black oat residue into the soil, and no-tillage system (NT), sowing maize nearly three weeks after chemical desiccation of black oat without residue incorporation. The treatments of both oat residue management systems were carried out on the same day. Six N management systems were assessed in the split-plots: S1 – control, without N application; S2 – all N applied on the day of oat desiccation; S3 – all N applied at maize sowing; S4 – all N side-dressed when maize had five expanded leaves (The V5 growth stage according to Ritchie et al., 1993); S5 – 1/3 of N rate applied at maize sowing and 2/3 at V5; S6 – 2/3 of nitrogen rate applied at maize sowing and 1/3 at V5. A nitrogen rate of 100 kg $ha^{-1}$ was broadcast on the soil surface using urea. Nitrogen was side-dressed on 11/26/1999, 11/18/2000 and 11/23/2001.

Each split plot had six rows, 0.75 cm apart and 7.0 m long. All measurements were taken from the four central rows, leaving borders of 0.5 m at each row end. The N management systems were always applied to the same experimental site in each growing season.

Black oat was sown in mid May and chemically desiccated (NT) or incorporated into the soil (CT) always at the end of September. Maize (single-cross hybrid DKB 909) was sown 20 to 23 days afterwards at a density of 75,000 plants $ha^{-1}$. On the sowing day, 80 kg $P_2O_5$ and 100 kg $ha^{-1}$ $K_2O$ was surface applied to the soil. Weeds and insects were chemically controlled when needed and the manual harvest always performed in April.

On the day the winter crop was desiccated, plant samples were taken using a square wooden box (0.5 $m^2$ m surface area). The samples were oven-dried at 65 °C and used to estimate oat dry mass yield and C/N ratio. Three weeks after maize emergence, five plants randomly chosen in the third row of each split-plot were marked with permanent ink. The tips of the fourth and eighth leaf of each plant were tagged, as a reference point to correctly estimate the total number of expanded leaves. These plants were also used to determine the number of green and senesced leaves at flowering.

Maize dry mass yield was evaluated at three growth stages: V6 (six expanded leaves), R1 (silking) and R6 (physiological grain maturity). Four randomly picked plants in the fifth row of each split plot were used to assess dry mass yield. These plants were ground and used to estimate shoot N concentration and N accumulation in the plant according to the methodology presented by Tedesco et al. (1995). Grain yield and yield components were determined based on plants harvested from each split-plot (9.0 $m^2$). Yield values were adjusted to 13% standard moisture. The agronomic efficiency of applied N ($AE_N$), described by Mosier et al. (2004), was calculated by the following expression: $AE_N$ (kg grain increase/kg applied N) = ($Y_N - Y_0/F_N$) where $Y_N$ is the crop yield at a certain level of N fertilizer applied (kg $ha^{-1}$), $Y_0$ is the crop yield measured in a treatment without N application and $F_N$ is the N rate (100 kg $ha^{-1}$).

The analysis of variance was performed separately for each growing season using the F test. The F values for the main treatment effects and their interactions were considered significant (at $P < 0.05$) and the treatment means compared using Duncan's test (at $P < 0.05$).

## RESULTS AND DISCUSSION

Total rainfall during maize growing seasons (October to April) ranged from 828 mm in 2001/2002 to 1.165 mm in 2000/2001 (Table 1). These values were higher than the crop evapotranspiration in southern Brazil, which varies from 550 to 690 mm, depending on the environmental conditions. Pluvial precipitation from the 2nd half of September to the end of the 1st half of November, a period that comprised N fertilization at oat desiccation (S2) and maize sowing (S3) and preceded N side-dress, was high, especially in 2000/2001 (466 mm) and 2001/2002 (375 mm). No significant period of water deficit at maize flowering was observed (January) in the whole experimental period.

No significant single effect of soil tillage and interaction between soil tillage and N management system was detected for the evaluated variables during the three experimental years. Consequently, the impacts of N timing and splitting are presented considering the mean values of conventional and no-tillage systems.

The lack of interaction between soil tillage and N management system contradicts the premise that no-tillage maize succeeding black oat requires larger amounts of N in the early crop development stages to compensate short-term N immobilization (Argenta et al., 1999). Oat dry mass yield at desiccation/incorporation ranged from 4.05 t $ha^{-1}$ (2001/2002) to 4.35 t $ha^{-1}$ (1999/2000). The winter crop C/N ratio varied from 37 (2000/2001) to 39 (2001/2002). The combination of high dry mass yield and a C/N ratio over 25–30 is favorable for short-term N immobilization. According to Below (2002), differences in N management practices, such as N dose or application timing, between no-tillage and conventional tillage system are only significant when N supply for maize is limited. Our data support this finding, showing that in clayey soils with high organic matter content the best time to apply N is not substantially affected by the soil tillage system. The same was observed by Torbert et al. (2001), who analyzed a Hust Black clayey soil in the US.

The application of all N after plant emergence (S4) reduced shoot dry mass at V6 in 2000/2001 and 2001/2002, compared to the systems where N was all applied during or before maize sowing (Table 2). An opposite trend was observed close to harvesting where postponing all N fertilization to V5 promoted higher shoot dry mass values at maize physiological maturity than anticipating N application to oat desiccation or maize sowing in 2000/2001 and 2001/2002. The performance of shoot dry mass confirmed observations of Ceretta et al. (2002a,b), Mai et al. (2003) and Wolshick et al. (2003). The anticipation of all N application to the time of oat desiccation or maize

**Table 1. Monthly pluvial precipitation from September to April in Lages, Southern Brazil, from 1999 to 2002**

| Month | Pluvial precipitation (mm) | | | | | | | | | Normal [1] |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1999/2000 | | | 2000/2001 | | | 2001/2002 | | | |
| | 1st half | 2nd half | Total | 1st half | 2nd half | Total | 1st half | 2nd half | Total | |
| September | 56.9 | 26.3 | 83.2 | 122.9 | 88.0 | 210.9 | 73.8 | 206.8 | 280.6 | 136.8 |
| October | 151.2 | 42.9 | 194.1 | 185.3 | 165.0 | 350.3 | 61.5 | 34.1 | 95.6 | 156.1 |
| November | 54.7 | 50.0 | 104.7 | 27.6 | 41.6 | 69.2 | 72.5 | 58.4 | 130.9 | 115.0 |
| December | 78.9 | 1.2 | 80.1 | 37.3 | 126.2 | 163.5 | 114.7 | 18.5 | 133.2 | 129.9 |
| January | 61.8 | 115.3 | 177.1 | 69.4 | 154.8 | 224.2 | 88.4 | 57.2 | 145.6 | 156.7 |
| February | 45.8 | 84.7 | 130.5 | 58.1 | 65.9 | 124.0 | 45.4 | 20.6 | 66.0 | 142.5 |
| March | 51.1 | 40.3 | 91.4 | 37.1 | 47.5 | 84.6 | 102.4 | 20.1 | 122.5 | 111.5 |
| April | 91.6 | 45.7 | 137.3 | 98.8 | 50.6 | 149.4 | 21.6 | 112.8 | 134.4 | 97.9 |

[1] Mean of the last 50 years in the region.

sowing enhanced maize dry mass accumulation during the early crop growth but did not ensure higher dry mass accumulation at harvest.

Shoot N uptake values ranged from 75.3 to 148.6 mg $pl^{-1}$ in V6 (Table 3). The values were generally higher for treatments with larger amounts of N applied before or at maize sowing. Nonetheless, there was no significant difference in shoot N content in V6 between S2, S3 and S5, showing that 30 kg $ha^{-1}$ N at planting (current recommendation) provided similar tissue N contents at higher N rates (S2, S3 and S6). Conversely, moving all N fertilization to the time of oat desiccation or sowing decreased maize N uptake at flowering in 2000/2001 and at grain physiological maturity in 2001/2002, when compared to the S4 and S5 management systems.

Total leaf number was not affected by N management system and varied little in the experimental period, ranging from 19.0 to 20.7 (Table 4). According to Sangoi et al. (2001b), the number of leaves is a strongly genotype-dependent trait, positively correlated with the number of thermal units each hybrid needs to flower. The control always had a lower number of green leaves and higher number of senesced leaves at flowering than the treatments that received N. In the first growing season, timing of N

**Table 2. Effect of N management systems on plant dry mass accumulation at three growth stages, considering the mean of two tillage systems**

| N system | Dry mass | | |
|---|---|---|---|
| | V6(1) | VT | R6 |
| | g $pl^{-1}$ | | |
| | | 1999/2000 | |
| S1- No N(2) | 1.94*b | 127 NS** | 229 b |
| S2- All at desiccation | 2.44 ab | 131 | 269 ab |
| S3- All at sowing | 2.85 a | 128 | 295 a |
| S4- All at V5 | 2.46 ab | 141 | 277 ab |
| S5- 1/3 + 2/3 | 2.25 ab | 121 | 276 ab |
| S6- 2/3 + 1/3 | 2.89 a | 133 | 289 ab |
| Mean | 2.47 | 130 | 272 |
| | | 2000/2001 | |
| S1- No N | 2.31 c | 107 c | 204 d |
| S2- All at desiccation | 2.84 abc | 113 bc | 228 cd |
| S3- All at sowing | 3.20 ab | 128 abc | 247 bc |
| S4- All at V5 | 2.32 c | 132 ab | 300 a |
| S5- 1/3 + 2/3 | 2.63 bc | 143 a | 264 b |
| S6- 2/3 + 1/3 | 3.29 a | 129 ab | 260 b |
| Mean | 2.76 | 125 | 251 |
| | | 2001/2002 | |
| S1- No N | 3.08 b | 104 c | 205 d |
| S2- All at desiccation | 4.13 a | 131 b | 273 c |
| S3- All at sowing | 3.95 a | 148 a | 300 b |
| S4- All at V5 | 3.17 b | 133 b | 314 a |
| S5- 1/3 + 2/3 | 4.17 a | 133 b | 317 a |
| S6- 2/3 + 1/3 | 4.16 a | 143 ab | 291 b |
| Mean | 3.77 | 132 | 283 |

(1) V6 – six expanded leaves; VT – tasseling; R6 – grain physiological maturity (after Ritchie et al., 1993). (2) S1- No N: without N application; S2- All at desiccation: all N applied before maize sowing at oat desiccation; S3- All at sowing: all N applied at maize sowing; S4- All at V5: all N side-dressed when maize plants were at V5; S5- 1/3 + 2/3: 1/3 of N rate applied at maize sowing and 2/3 side-dressed at V5; S6- 2/3 + 1/3: 2/3 of N rate applied at maize sowing and 1/3 side-dressed at V5. * Means followed by the same lower case letter in the column, for each growth stage within each year, are not significantly different by Duncan's test ($P < 0.05$). ** NS – no significant differences at $P < 0.05$.

**Table 3. Effect of N management systems on N uptake per plant by maize shoot at two growth stages (V6 and VT) and by grain at physiological maturity (R6), considering the mean of the two tillage systems**

| N system | N uptake | | |
|---|---|---|---|
| | V6[1] | VT | R6 |
| | mg $pl^{-1}$ | g $pl^{-1}$ | |
| | | 1999/2000 | |
| S1- No N[2] | 80.0*b | 2.52 NS | 0.91 NS** |
| S2- All at desiccation | 100.6 ab | 3.01 | 1.25 |
| S3- All at sowing | 106.9 ab | 3.16 | 1.06 |
| S4- All at V5 | 81.2 b | 3.50 | 1.32 |
| S5- 1/3 + 2/3 | 89.1 ab | 2.86 | 1.19 |
| S6- 2/3 + 1/3 | 118.7 a | 3.25 | 1.22 |
| Mean | 96.1 | 3.05 | 1.16 |
| | | 2000/2001 | |
| S1- No N | 75.3 c | 1.49 c | 0.92 b |
| S2- All at desiccation | 101.1 abc | 1.63 bc | 0.93 b |
| S3- All at sowing | 116.3 ab | 2.01 b | 1.14 b |
| S4- All at V5 | 90.4 bc | 2.85 a | 1.58 a |
| S5- 1/3 + 2/3 | 95.8 abc | 2.96 a | 1.48 a |
| S6- 2/3 + 1/3 | 118.3 a | 2.59 ab | 1.15 b |
| Mean | 99.5 | 2.25 | 1.20 |
| | | 2001/2002 | |
| S1- No N | 97.3 b | 1.39 c | 0.71 c |
| S2- All at desiccation | 145.0 a | 2.38 b | 0.96 b |
| S3- All at sowing | 133.2 a | 3.08 a | 1.02 b |
| S4- All at V5 | 110.7 b | 3.07 a | 1.18 a |
| S5- 1/3 + 2/3 | 133.2 a | 2.79 a | 1.17 a |
| S6- 2/3 + 1/3 | 148.6 a | 2.91 a | 1.08 ab |
| Mean | 128 | 2.60 | 1.02 |

[1] V6 – six expanded leaves; VT – tasseling; R6 – grain physiological maturity (after Ritchie et al., 1993). [2] S1- No N: without N application; S2- All at desiccation: all N applied before maize sowing at oat desiccation; S3- All at sowing: all N applied at maize sowing; S4- All at V5: all N side-dressed when maize plants were at V5; S5- 1/3 + 2/3: 1/3 of N rate applied at maize sowing and 2/3 side-dressed at V5; S6- 2/3 + 1/3: 2/3 of N rate applied at maize sowing and 1/3 side-dressed at V5. * Means followed by the same lower case letter in the column, for each growth stage within each year, are not significantly different by Duncan's test ($P < 0.05$). ** NS – no significant differences at $P < 0.05$.

application did not alter the number of green and senesced leaves at flowering. During the subsequent years, side-dressing all N at V5 (S4) maintained the highest number of green leaves at flowering. Especially in years with early rainy springs, such as 2000/2001 (Table 1), N application before or at sowing (S2, S3) hastened leaf senescence, forcing the crop to flower with a lower number of green leaves.

The anticipation of N fertilization stimulated the early crop growth favoring N uptake and increasing plant dry mass at the beginning of the maize reproductive period. On the other hand, the advantages of supplying all N before the beginning of the root system development disappeared at flowering. Nearly 75% of total N accumulated at harvest is taken up by maize from tassel differentiation (which happens close to V6) to silking (Bull, 1993).

Based on rainfall recorded from the end of September (oat desiccation) to the second half of November (N side-dress) and on shoot N uptake until flowering (Tables 1 and 3), it is possible to infer that in the growing seasons with wet early springs (2000/2001 and 2001/2002) the application of 100 kg of N at oat desiccation or at maize sowing probably favored

**Table 4. Effect of N management systems on the number of leaves presented by maize at flowering (when the silks of at least 50 % of the plants on each split plot are visible), considering the mean of the two tillage systems**

| N system | Total leaves | Green Leaves | Senesced leaves |
|---|---|---|---|
| | number per plant | | |
| | | 1999/2000 | |
| S1- No N(1) | 20.5 **NS | 12.3 *c | 8.2 a |
| S2- All at desiccation | 20.7 | 13.6 ab | 7.1 b |
| S3- All at sowing | 20.7 | 13.8 a | 6.9 b |
| S4- All at V5 | 20.6 | 13.6 ab | 7.0 b |
| S5- 1/3 + 2/3 | 20.6 | 13.2 b | 7.4 b |
| S6- 2/3 + 1/3 | 20.9 | 13.9 a | 7.0 b |
| Mean | 20.7 | 13.4 | 7.3 |
| | | 2000/2001 | |
| S1- No N | 19.4 NS | 11.4 d | 8.0 a |
| S2- All at desiccation | 19.1 | 11.7 d | 7.4 b |
| S3- All at sowing | 19.1 | 11.5 d | 7.6 b |
| S4- All at V5 | 19.3 | 13.7 a | 5.6 d |
| S5- 1/3 + 2/3 | 19.2 | 13.1 b | 6.1 c |
| S6- 2/3 + 1/3 | 19.0 | 12.5 c | 6.5 c |
| Mean | 19.2 | 12.3 | 6.9 |
| | | 2001/2002 | |
| S1- No N | 19.1 NS | 9.8 c | 9.3 a |
| S2- All at desiccation | 19.2 | 10.4 b | 8.8 b |
| S3- All at sowing | 19.1 | 10.3 b | 8.8 b |
| S4- All at V5 | 19.4 | 10.9 a | 8.5 b |
| S5- 1/3 + 2/3 | 19.0 | 10.3 b | 8.7 b |
| S6- 2/3 + 1/3 | 19.0 | 10.4 b | 8.6 b |
| Mean | 19.1 | 10.3 | 8.8 |

(1) S1- No N: without N application; S2- All at desiccation: all N applied before maize sowing at oat desiccation; S3- All at sowing: all N applied at maize sowing; S4- All at V5: all N side-dressed when maize plants were at V5; S5- 1/3 + 2/3: 1/3 of N rate applied at maize sowing and 2/3 side-dressed at V5; S6- 2/3 + 1/3: 2/3 of N rate applied at maize sowing and 1/3 side-dressed at V5. * Means followed by the same lower case letter in the column within each year are not significantly different by the Duncan's test ($P < 0.05$). ** NS – no significant differences at $P < 0.05$.

N leaching, decreasing the amount of N available in the soil from V6 to VT. The smaller number of green leaves recorded in the S2 and S3 systems, compared to S4, in the last two growing seasons, further reinforces this hypothesis.

Grain yields ranged from 6.04 to 11.76 t ha$^{-1}$ (Table 5), with a three-year average of 9.8 t ha$^{-1}$. The impact of N fertilization on grain yield increased from the beginning towards the end of the experimental period. Compared to the control, N addition increased grain yield by 18% (1.71 t ha$^{-1}$) in 1999/2000, and by 40% (3.01 t ha$^{-1}$) and 47% (2.84 t ha$^{-1}$), respectively, in the following years. The continuous succession of grass species (black oat and maize) over three years in the same area probably improved grain yield response to N fertilization at the end of the experimental period.

The anticipation of N fertilization to the time of oat desiccation or maize sowing decreased grain yield compared with the treatment where all N was applied in V5, in two out of three years. In the rainiest early spring season (2000/2001), the application of all N at V5 (S4) promoted an yield advantage of 2.2 t ha$^{-1}$ over the systems where the whole N rate was anticipated (S2 and S3). The application of N before or at maize sowing decreased the number of kernels per ear in 2000/2001 and in 2001/2002, and the number of ears produced per area in 2001/2002 (Table 5), contributing to decrease grain yield in the S2 and S3 N

**Table 5. Effect of N management systems on maize grain yield and its components, considering the mean of two tillage systems**

| N system | Grain yield | Weight of 1,000 grains | Grains per ear | Ears per plant | Weight of grains per ear |
|---|---|---|---|---|---|
| | t ha$^{-1}$ | g | number | number | g |
| | | | 1999/2000 | | |
| S1- No N[(1)] | 9.48*b | 314 b | 412 b | 1.01 b | 130 b |
| S2- All at desiccation | 10.87 a | 340 a | 445 a | 1.09 a | 151 a |
| S3- All at sowing | 11.19 a | 339 a | 448 a | 1.07 a | 152 a |
| S4- All at V5 | 11.75 a | 339 a | 462 a | 1.06 a | 157 a |
| S5- 1/3 + 2/3 | 11.12 a | 331 a | 463 a | 1.07 a | 153 a |
| S6- 2/3 + 1/3 | 11.04 a | 335 a | 455 a | 1.06 a | 152 a |
| Mean | 10.91 | 333 | 447 | 1.06 | 149 |
| | | | 2000/2001 | | |
| S1- No N | 7.48 d | 322 **NS | 312 d | 0.99 b | 101 d |
| S2- All at desiccation | 9.54 c | 321 | 389 c | 1.02 ab | 125 bc |
| S3- All at sowing | 9.59 c | 328 | 373 c | 1.00 b | 118 c |
| S4- All at V5 | 11.76 a | 332 | 461 a | 1.03 ab | 153 a |
| S5- 1/3 + 2/3 | 11.20 ab | 324 | 435 ab | 1.03 ab | 141 ab |
| S6- 2/3 + 1/3 | 10.37 bc | 317 | 413 bc | 1.07 a | 131 bc |
| Mean | 9.19 | 324 | 397 | 1.02 | 128 |
| | | | 2001/2002 | | |
| S1- No N | 6.04 c | 283 b | 312 c | 0.96 b | 77 b |
| S2- All at desiccation | 8.56 b | 297 ab | 414 b | 0.98 b | 107 a |
| S3- All at sowing | 8.59 b | 304 a | 412 b | 0.97 b | 112 a |
| S4- All at V5 | 9.50 a | 305 a | 435 a | 1.04 a | 115 a |
| S5- 1/3 + 2/3 | 8.81 ab | 306 a | 416 ab | 0.98 b | 111 a |
| S6- 2/3 + 1/3 | 8.95 ab | 307 a | 409 b | 1.00 ab | 109 a |
| Mean | 8.41 | 300 | 400 | 0.99 | 105 |

[(1)] S1- No N: without N application; S2- All at desiccation: all N applied before maize sowing at oat desiccation; S3- All at sowing: all N applied at maize sowing; S4- All at V5: all N side-dressed when maize plants were at V5; S5- 1/3 + 2/3: 1/3 of N rate applied at maize sowing and 2/3 side-dressed at V5; S6- 2/3 + 1/3: 2/3 of N rate applied at maize sowing and 1/3 side-dressed at V5. * Means followed by the same lower case letter in the column within each year are not significantly different by Duncan's test ($P < 0.05$). ** NS – no significant differences at $P < 0.05$.

management systems. The weight of 1,000 grains was a more stable yield component and was not affected by the time of N fertilization.

Each kilogram of N applied to the soil increased grain yield ($AE_N$) from 13.9 to 38.8 kg, depending on the N management system and growing season (Table 6). In all three seasons, one of the most efficient forms to manage N fertilization to produce grains was to side-dress the whole N rate in V5. An additional advantage of S4 is to apply all N in a single operation once split fertilization is more labor-intensive and increases fuel consumption. On the other hand, concentrating N fertilization at black oat desiccation or maize sowing decreased $AE_N$. An adequate N supply at flowering is fundamental to maintain a high number of photosynthetic active leaves, to delay leaf senescence and to raise the number of fertilized ovules (Earl & Tollenaar, 1997). It is possible that high rainfall from mid September to mid November decreased soil N availability during maize flowering when all N fertilization was moved to the beginning of the growing season. This may have contributed to decrease the number of kernels produced per ear in 2000/2001 and 2001/2002, reducing grain yield and $AE_N$ in comparison to the treatment where N was fully side-dressed at V5. Reductions in maize grain yield caused by the anticipation of N fertilization in wet spring conditions were reported by Bortolini et al. (2000, 2001), Scherer (2001), Basso & Ceretta (2000) Ceretta et al. (2002a,b), Mai et al. (2003) and Wolschick et al. (2003).

**Table 6. Effect of N fertilizer systems on agronomic efficiency of applied N ($AE_N$)[1] in maize, considering the mean of the two tillage systems**

| N system | Season | | |
|---|---|---|---|
| | 1999/2000 | 2000/2001 | 2001/2002 |
| S1- No N[2] | - | - | - |
| S2- All at desiccation | 13.9 c | 18.7*c | 23.3 b |
| S3- All at sowing | 17.1 b | 19.8 c | 23.2 b |
| S4- All at V5 | 22.6 a | 38.8 a | 31.4 a |
| S5- 1/3 + 2/3 | 16.4 b | 33.8 ab | 25.0 ab |
| S6- 2/3 + 1/3 | 15.7 b | 27.1 bc | 26.2 ab |
| Mean | 17.1 | 27.6 | 25.8 |

[1] $AE_N = (Y_N - Y_0/F_N)$ where $Y_N$ is the crop yield at a certain level of fertilizer N applied (kg ha$^{-1}$), $Y_0$ is the crop yield measured in a treatment with N application and $F_N$ is the N rate (100 kg ha$^{-1}$. [2] S1- No N: without N application; S2- All at desiccation: all N applied before maize sowing at oat desiccation; S3- All at sowing: all N applied at maize sowing; S4- All at V5: all N side-dressed when maize plants were at V5; S5- 1/3 + 2/3: 1/3 of N rate applied at maize sowing and 2/3 side-dressed at V5; S6- 2/3 + 1/3: 2/3 of N rate applied at maize sowing and 1/3 side-dressed at V5. * Means followed by the same lower case letter in the column within each year are not significantly different by Duncan's test ($P < 0.05$).

The grain yield values obtained with the S4 N management system over the whole experimental period indicates that side-dressing all N when plants had five expanded leaves did not jeopardize maize nutrient uptake from the soil or high yields. Our data evidence that short term N immobilization was not a key factor to reduce grain yield when no N was applied at maize sowing, regardless of the soil tillage system. This contradicts the proposal of Sá (1997) to move the time of N application from the traditional side-dress in V5 to the time of winter crop desiccation or maize sowing following black oat in no-till tillage systems. Three reasons may explain our results. The Oxisol had more than 50 g kg$^{-1}$ of organic matter, which probably inhibited N immobilization caused by the oat residues with high C/N ratio. Argenta et al. (1999), evaluating the response of grain yield to the timing of N application in two soils, found detrimental effects of side-dressing all N in V5 only when maize was grown under no-tillage after black oat in the soil with less than 30 g kg$^{-1}$ organic matter.

Another aspect to consider is the time between oat desiccation and maize sowing. Nitrogen immobilization is a short-term process that is quite intense in the first 30 days after winter crop incorporation or desiccation (Torbet et al., 2001; Ernani et al., 2002). One strategy to minimize this process and its detrimental effect on grain yield is to avoid sowing maize right after black oat desiccation. Argenta et al. (1999) observed that waiting 20 days after oat desiccation until maize sowing is an efficient strategy to accelerate the decomposition of oat straw and to decrease its negative impact on maize growth. In our study, there was always an interval of at least three weeks between oat incorporation/desiccation and maize sowing. This probably attenuated the competition between soil microorganisms and maize for nitrogen.

Finally, the reduced period of early crop growth, usually observed with delayed N application when maize is sown after black oat, has less effect on grain yield when corn is planted in the beginning of spring (Russele et al., 1983; Scharf et al., 2002). At this time, air temperatures are low and maize grows slowly, which gives the crop more time to recover from early cycle stresses without compromising the formation of yield component (Sangoi, 1993). This experiment was sown in the beginning of the growing season (second half of October) at mild temperatures, ranging from 15 to 25 °C (data not shown), until plants reached the flowering stage.

## CONCLUSION

The risk of yield loss associated with the concentration of N fertilization in V5 due to immobilization is low even when maize is sown after black oat in soils with high organic matter content. The anticipation of N fertilization may be a feasible alternative in years when rainfall in the spring season is not very high. However, reasonable care must be taken to check the strategy of concentrating the whole N application before or at maize sowing. It can decrease the amount of available N when the crop has a high internal demand, which rushes leaf senescence, decreases the number of kernels per ear, limits grain yield and, ultimately, impairs the agronomic efficiency of applied N.

## LITERATURE CITED


AMADO, T.J.C.; MIELNICZUCK, J. & VEZZANI, F.M. Nova recomendação de adubação nitrogenada para o milho sob plantio direto no RS e SC adaptada ao uso de cobertura do solo. R. Plantio Direto, 3:30-35, 2002.

ANDROSKI, T.W.; BUNDY, L.G. & BRYE, K.R. Crop management and corn nitrogen rate effects on nitrate leaching. J. Environ. Qual., 29:1095-1103, 2000.

ARGENTA, G.; SILVA, P.R.F.; RIZZARDI, M.A.; BARUFFI, M.A. & BEHEREGARAY NETO, V. Manejo do nitrogênio do milho em semeadura direta em sucessão a espécies de cobertura de solo no inverno e em dois locais. I. Efeito sobre a absorção de N. Ci. Rural., 29:577-586, 1999.

BASSO, C.J. & CERETTA, C.A. Manejo do nitrogênio no milho em sucessão a plantas de cobertura de solo, sob plantio direto. R. Bras. Ci. Solo, 24:905-915, 2000.

BAYER, C. & MIELNICZUK, J. Características químicas do solo afetadas por métodos de preparo e sistemas de cultura. R. Bras. Ci. Solo, 21:105-112, 1997.

BELOW, F.E. Fisiologia, nutrição e adubação nitrogenada do milho. Inf. Agron., 99:7-12, 2002.

BLACKMER, A.M.; MORRIS, T.F. & BINFORD, G.D. Predicting N fertilizer needs for corn in humid regions: advances in Iowa. In: BOCK, B.R. & KELLEY, K.R., eds. Predicting N fertilizer needs in humid regions. Ames, National Fertilizer and Environmental Research Center, 1992. p.58-72.

BORTOLINI, C.G.; SILVA, P.R.F. & ARGENTA, G. Sistemas consorciados de aveia preta e ervilhaca comum como cobertura de solo e seus efeitos na cultura do milho em sucessão. R. Bras. Ci. Solo, 24:897-903, 2000.

BORTOLINI, C.G.; SILVA, P.R.F.; ARGENTA, G. & FORSTHOFER, E.L. Rendimento de grãos de milho cultivado após aveia preta em resposta a adubação nitrogenada e regime hídrico. Pesq. Agropec. Bras., 36:1101-1106, 2001.

BULL, L.T. Nutrição mineral do milho. In: BULL, L.C., ed. Cultura do milho: Fatores que afetam a produtividade. Piracicaba, Potafós, 1993. p.63-146.

CERETTA, C.A. & FRIES, M.R. Adubação nitrogenada no sistema de plantio direto. In: FRIES, M.R. & DALMOLIN, R.S.D., eds. Atualização em recomendação de adubação e calagem: Ênfase em plantio direto. Santa Maria, Universidade Federal de Santa Maria, 1997. p.112-124.

CERETTA, C.A.; BASSO, C.J.; FLECHA, A.M.T.; PAVINATO, P.S.; VIEIRA, F.C.B. & MAI, M.E.M. Manejo da adubação nitrogenada na sucessão aveia preta/milho, no sistema plantio direto. R. Bras. Ci. Solo, 26:163-171, 2002a.

CERETTA, C.A.; BASSO, M.J.; HERBES, M.G.; POLETTO, N. & SILVEIRA, M.J. Produção e decomposição de fitomassa de plantas hibernais de cobertura de solo e milho, sob diferentes manejos da adubação nitrogenada. Ci. Rural, 32:49-54, 2002b.

COMISSÃO DE FERTILIDADE DO SOLO-CFSRS/SC. Recomendações de adubação e calagem para os estados do Rio Grande do Sul e Santa Catarina. Porto Alegre, SBCS-Núcleo Regional Sul, 2004. 394p.

DINNES, D.L.; KARLEN, D.L.; JAYBES, D.B.; KASPAR, T.C.; HATFIELD, J.L.; COLVIN, T.S. & CAMBARDELLA, C.A. Nitrogen management strategies to reduce nitrate leaching in tile-drained midwestern soils. Agron. J., 94:153-171, 2002.

EARL, H.J. & TOLLENAAR, M. Maize leaf absorptance of photosynthetically active radiation and its estimation using a chlorophyll meter. Crop Sci., 37:436-440, 1997.

ERNANI, P.R., Disponibilidade de nitrogênio e adubação nitrogenada para a macieira. Lages, Graphel, 2003. 76p.

ERNANI, P.R.; SANGOI, L. & RAMPAZZO, C. Lixiviação e imobilização de nitrogênio num Nitossolo como variáveis da forma de aplicação da uréia e da palha de aveia. R. Bras. Ci. Solo, 26:993-1000, 2002.

KUO, S. & JELLUM, E.J. Influence of winter cover crop and residue management on soil nitrogen availability in corn. Agron. J., 94:501-508, 2002.

LECH, V.A. Perdas de N e resposta do milho à adubação nitrogenada afetadas por sistemas de manejo dos restos culturais de aveia preta. Lages, Universidade do Estado de Santa Catarina, 2001. 85p. (Tese de Mestrado)

MAI, E.M.M.; CERETTA, C.A.; BASSO, C.J.; SILVEIRA, M.J.; PAVINATO, A. & PAVIANATO, S. Manejo da adubação nitrogenada na sucessão aveia preta/milho no sistema plantio direto. Pesq. Agropec. Bras., 38:125-131, 2003.

MOSIER, A.R.; SYERS, J.K. & FRENEY, J.R. Agriculture and the nitrogen cycle – assessing the impacts of fertilizer use on food production and the environment. Washington, Island Press, 2004. (Scope report, 65)

MUZZILI,O. & OLIVEIRA, A. Nutrição e adubação. In: INSTITUTO AGRONÔMICO DO PARANÁ. O milho no Paraná. Londrina, 1992. p.88-95.

RITCHIE, S.W.; HANWAY, J.J. & BENSON, G.O. How a corn plant develops. Ames, Iowa State University of Science and Technology, 1993. 26p. (Special Report, 48)

RUSSELE, M.P.; HAUCK, R.D. & OLSON, R.A. Nitrogen accumulation rates of irrigated corn. Agron. J., 75:593-598, 1983.

SÁ, J.C.M. Manejo do nitrogênio na cultura do milho no sistema de plantio direto. In: FANCELLI, A.L. & DOURADO-NETO, D., eds. Tecnologia de produção de milho. Piracicaba, Escola Superior de Agricultura Luiz de Queiroz, 1997. p.84-103.

SANGOI, L. Aptidão dos campos de Lages para produção de milho em diferentes épocas de semeadura. Pesq. Agropec. Bras., 28:51-63,1993.

SANGOI, L.; ALMEIDA, M.L.; LECH, V.A.; GRACIETTI, L.C. & RAMPAZZO, C. Desempenho de híbridos de milho com ciclos contrastantes em função da desfolha e da população de plantas. Sci. Agric., 58:271-276, 2001b.

SANGOI, L.; ENDER, M.; GUIDOLIN, A.F. & KONFLANZ, V.A. Nitrogen fertilization impact on agronomic traits of maize hybrids released at different decades. Pesq. Agropec. Bras., 36:757-764, 2001a.

SCHERER, E.E. Avaliação de fontes e épocas de aplicação do adubo nitrogenado na cultura do milho no sistema plantio direto. Agropec. Catarinense, 14:48-53, 2001.

SCHARF, P.C.; WIEBOLD, W.J. & LORY, J.A. Corn yield response to nitrogen fertilizer timing and deficiency level. Agron. J., 94:435-441, 2002.

TEDESCO, M.J.; VOLKSVEISS, S.J. & BOHEN, H. Análise de solo, plantas e outros materiais. Porto Alegre, Universidade Federal do Rio Grande do Sul, 1995. 188p. (Boletim Técnico, 5)

TORBERT, H.A. & WOOD, C.A. Effects of soil compaction and water-filled pore space on soil microbial activity and N losses. Comm. Soil Sci. Plant Anal., 23:1321-1331, 1992.

TORBERT, H.A.; POTTER, K.N. & MORRISON JR., J.E. Tillage system, fertilizer nitrogen rate, and timing effect on corn yields in the Texas Blackland Prairie. Agron. J., 93:1119-1124, 2001.

WOLSHICK, D.; CARLESSO, R.; PETRY, M.T. & JADOSKI, S.O. Adubação nitrogenada na cultura do milho no sistema plantio direto em ano com precipitação normal e com “el nino”. R. Bras. Ci. Solo, 27:461-468, 2003.